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Centripetal Accelerations at the Playground

The portability of the LabPro and CBL 2 interfaces makes them good tools for studying phenomena that occur outside the laboratory. Two situations present themselves at a typical playground: a swing and a merry-go-round. A rider on a merry-go-round can be an example of uniform circular motion, while the seat of a swing moves at varying speeds along a circular path. Since both cases involve circular motion, there must be a centripetal acceleration in each situation. You can measure these accelerations with a portable interface and an Accelerometer.

From your own experience on swings, you probably know that at the bottom of each swing the rider experiences the largest acceleration. You can measure the acceleration at this point with an Accelerometer. You can also calculate another value for the acceleration based on energy conservation, and then compare the two values.

On a merry-go-round, you can measure the centripetal acceleration as a function of angular speed or radius. These values can be checked against values of the acceleration based on kinematics measurements.

OBJECTIVES

- Measure acceleration in two real-world settings.
- Compare the measured acceleration to the value calculated from other data.

MATERIALS

LabPro or CBL 2 interface	masking tape
TI Graphing Calculator	stopwatch
DataMate program	measuring tape
Vernier Low-g Accelerometer	inclinometer (optional)

PRELIMINARY QUESTIONS

1. When riding a playground swing, at what point in the motion do you feel the greatest force? Why do you feel the greatest force at that point?
2. On a merry-go-round, does the centripetal acceleration depend upon the radius if the ride is rotating at a constant rate? Why do you think so?

GENERAL PROCEDURE

The following steps will guide you through configuring the interface to collect acceleration data so that you need to carry only the interface and sensor. After collecting data, the calculator is reconnected and data are then transferred for graphing and analysis.

You will probably need to modify either the time between samples or the number of points collected for your particular circumstances. Adjust these values as you design your experiment.

1. Connect the Vernier Accelerometer to Channel 1 on the LabPro or CBL 2 interface. Use the black link cable to connect the interface unit to the TI Graphing Calculator. Firmly press in the cable ends.

2. Turn on the calculator. Start the DATAMATE program and press CLEAR to reset the program.

3. If CH 1 displays the Accelerometer and its current reading, skip the remainder of this step. If not, set up DATAMATE for the sensor manually. To do this,
   a. Select SETUP from the main screen.
   b. Press ENTER to select CH 1.
   c. Select ACCELEROMETER from the SELECT SENSOR list.
   d. Select LOW G ACCEL (M/S^2) from the ACCELEROMETER list.
   e. Select OK to return to the main screen.

4. Set up the calculator and interface for remote data collection.
   a. Select SETUP from the main screen.
   b. Press ▲ to select MODE and press ENTER.
   c. Select TIME GRAPH from the SELECT MODE screen.
   d. Select CHANGE TIME SETTINGS from the TIME SETTINGS screen.
   e. Enter "0.2" as the time between samples in seconds for the swing, and "0.5" for the merry-go-round. You may want to change this value according to your experimental conditions. Remember to finish your entry with ENTER.
   f. Enter "100" as the number of samples. You may want to change this value according to your experimental conditions. For example, estimate the desired time interval for data collection, and divide by the number of points you will collect. The result is the time between samples. (The TI-83 Plus, 86, 89, and 92 Plus will allow you to collect more than 500 points, which will be enough for most purposes. The TI-73, 83 and 92 will allow up to 100 points. For all calculators the maximum number of points will be reduced if other programs or variables occupy memory.)
   g. Select ADVANCED from the TIME GRAPH SETTINGS screen.
   h. Select CHANGE TRIGGERING from the ADV. TIME GRAPH SETTINGS screen.
   i. Select MANUAL TRIGGER from the SELECT TRIGGERING screen.
   j. Select OK three times to return to the main screen.

5. Zero the Accelerometer in the orientation you plan to collect data. For example, if the accelerometer is to be oriented horizontally during data collection (such as on the merry-go-round), place the sensor on a horizontal surface with the arrow horizontal. Or, if you will be collecting data with the sensor oriented vertically (such as at the bottom of the swing motion), then place the sensor against a vertical surface with the arrow pointing upward.
   a. Select SETUP from the main screen.
   b. Select ZERO.
   c. Select CH1-ACCEL(M/S^2) from the SELECT CHANNEL screen.
   d. Orient your Accelerometer as appropriate for your experiment. With the sensor motionless, press ENTER to mark the zero condition.

6. You are now ready to collect acceleration data. This experiment is different from most you have performed with the LabPro or CBL 2 interface. In this case you will disconnect the interface from the calculator. Data collection will not begin until you press the START/STOP button on the interface. At the end of data collection, the data are stored in the interface until you retrieve them.
   a. Select START from the main screen. This will prepare the interface to collect data later; the interface will not start data collection at this time. Notice the message on the calculator screen.
   b. Press ENTER to return to the main screen.
   c. Select QUIT to leave the DataMate program.
   d. Disconnect the black link cable from the interface. You do not need to carry the calculator during data collection.
7. Orient the Accelerometer as appropriate for your experiment, and collect data when you are ready by pressing the START/STOP key on the interface. The interface will beep at the start and at the end of data collection.
8. Use the calculator to retrieve data from the interface:
   a. Reconnect the calculator to the interface using the black link cable. Firmly press in the cable ends.
   b. Start the DATAMATE program. After the opening title screen, the calculator will display a message showing that data collection is complete.
   c. Press ENTER on the calculator.
   d. Select TOOLS from the main screen.
   e. Select RETRIEVE DATA from the TOOLS screen. Data will be transferred from the interface to your calculator.
   f. Examine the graph of acceleration *vs.* time.
   g. Trace along the graph with the cursor keys to read out particular values.
   h. Press ENTER to return to the main screen.

PROCEDURE FOR MERRY-GO-ROUND

1. Use masking tape to mark the location of several radii along one of the pipes running outwards from the hub of the merry-go-round. Select an increment that will give you four different radii for your particular merry-go-round. Record these radii in your Data Table.
2. Follow the procedure described previously to set up the interface for data collection. Use a sample time interval of 0.50 s and 100 data points. This gives 50 seconds to collect your data. In Step 5, zero the Accelerometer with the arrow held horizontally.
3. Get on the merry-go-round and spin it to a constant speed. Practice maintaining this speed even if the experimenter on the ride moves inwards or outwards. Use the stopwatch to measure the time it takes for multiple rotations, then divide to determine the time for a single rotation. Record the period of rotation in the Data Table. This step can be completed while accelerations are being measured.
4. Hold the accelerometer at the first measured location, with the arrow horizontal and pointing toward the center of the merry-go-round. Start the data collection by pressing the START/STOP button on the interface.

5. After holding the accelerometer in this position for 5–10 seconds, move it to the second measured point, holding it there for a similar time. Continue moving to succeeding positions until you have collected data at all of your measured positions. Hold the speed of the merry-go-round constant.
6. Retrieve data from the interface and display the acceleration *vs.* time graph.

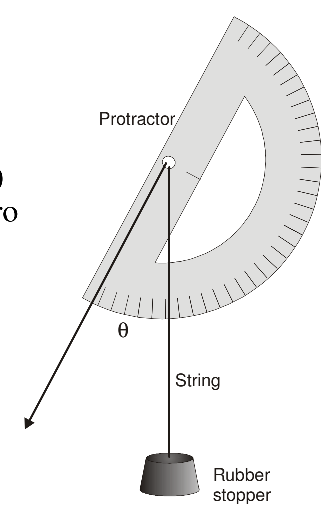
DATA TABLE

Period of Rotation (sec):			
Measurement	Radius (m)	Acceleration (m/s^2)	Predicted acceleration (m/s^2)
1			
2			
3			
4			

ANALYSIS

1. The interface data should show plateaus for each of the locations you used along the merry-go-round's radius. Determine an average acceleration value for each plateau and enter this value into the Data Table.
2. For each radius, the period will be the same if you maintained a constant angular speed. Centripetal acceleration in terms of radius, R, and period of rotation, T, is given by $4\pi^2R/T^2$. Calculate the value for each radius, and compare the calculated values with those you measured directly with the interface.
3. Plot the acceleration *vs*. radius for the merry-go-round. How would you describe the relationship shown on the graph? How does this agree with the relationship in the previous step? What are the units of the slope of a fitted line to these data?

PROCEDURE FOR SWING



1. Set up the interface and accelerometer for data collection as described above. Some experimentation may be needed to get a good combination of sample time and number of points for your specific swing set, but start with 0.20 s between points. With 100 points, you will have 20 seconds of data collection. In Step 5, zero the Accelerometer when the arrow is pointed upward.
2. Pump the swing. Maintain a constant amplitude. If you measure the angle from the vertical, use an inclinometer. If you measure the maximum height, record both that value and the minimum height in the Data Table.
3. Hold the accelerometer so its axis is directed along the chain supporting the swing. Start data collection by pressing the START/STOP button on the interface.

4. Record the maximum angle θ for each run in your Data Table.
5. Use the procedure from above to download the data from the interface and display the acceleration *vs.* time graph.
6. While tracing the graph, determine the maximum acceleration that occurs at the bottom of the swing arc. Record the value in your Data Table.
7. Repeat using a different starting angle, another rider, or different length. (Hold the accelerometer at a different point relative to the pivot point.)

DATA TABLE

Trial	Angle, θ (°)	Calculated Maximum Acceleration (m/s^2)	Predicted Maximum Acceleration (m/s^2)
1			
2			

ANALYSIS

1. Determine the tangential speed v of the rider at the bottom of the swing using energy considerations. At an angle θ, the rider will be ($L - L\cos\theta$) higher than at the bottom. Convert the gravitational potential energy at this point into kinetic energy at the bottom and find an expression for the velocity. Just find the algebraic expression; a number is not needed here.
2. Kinematics tells you that the centripetal acceleration is $a_c = v^2/r$. From the expression for the speed v find an expression, in terms of the maximum angle θ, for the centripetal acceleration at the bottom of a swing of length L. Using each value for the maximum angle θ, calculate a value for the predicted acceleration and enter it in the Data Table.
3. Compare the result you get from your calculation with the acceleration you measured. Discuss any sources of error that may have affected your results.
4. If you made modifications between trials, discuss the results and how they compare with your original value.

EXTENSIONS

1. For the playground swing, the pattern of accelerations can be studied and the period of the swing determined. A value for the period can be predicted from dynamics using $T = 2\pi\,(L/g)^{1/2}$. Compare this value to the interface acceleration data. For a seated rider, from what point should the rider's mass be measured when comparing the period to the predicted period for a simple pendulum (with a point mass) of $T = 2\pi\,(L/g)^{1/2}$? Compare this to the location of the person's center of mass when standing.
2. If you hold the accelerometer at the same location along the swing, but change the mass of the rider, how does this affect the period of the swing? Large changes in mass may be needed to see a change, if any.

3. Decay in amplitude can be observed by allowing the swing to gradually slow down due to air resistance and friction. As it slows, the maximum values of acceleration will decrease. Are the data from this decay similar to classical decays such as radioactivity? Is the decrease an exponential decay?

4. A similar decay can be observed on a merry-go-round when the push needed to maintain rotational motion is removed. The Accelerometer needs to remain at one point throughout, and the objects (bodies) on the merry-go-round must stay in position throughout the slowing down.

5. Changes in the rate of decay of the angular speed can be observed on the merry-go-round, depending upon the number and arrangement of people on the ride. How does the rate of decay depend upon both the number and location of the people?